

(NASA-CR-189437) NASA TROPICAL
RAINFALL MEASUREMENT MISSION
(TRMM): EFFECTS OF TROPICAL
RAINFALL ON UPPER OCEAN DYNAMICS,
AIR-SEA COUPLING AND HYDROLOGIC
CYCLE Final Report (Science
Applications) 9 p

N95-31123

Unclass

G3/47 0058470

NASA Tropical Rainfall Measurement Mission (TRMM)

Final Report: Contract NAS5-31458 3/358

Effects of Tropical Rainfall on Upper Ocean Dynamics, Air-Sea Coupling and Hydrologic Cycle

Principal Investigator

DR. GARY LAGERLOEF, Science Applications International Corporation
13400 Northup Way NE, Suite 36B, Bellevue, WA 98005
Telephone: (206)747-7152 FAX: (206)747-9211

Co-Investigators

Antonio J. Busalacchi (GSFC), W. Timothy Liu (JPL), Roger B. Lukas (U. Hawaii), Pearn P. Niiler (UCSD), Calvin T. Swift (U. Mass.)

Summary This was a Tropical Rainfall Measurement Mission (TRMM) modeling, analysis and applications research project. Our broad scientific goals addressed three of the seven TRMM Priority Science Questions, specifically:

What is the monthly average rainfall over the tropical ocean areas of about 10^5 km²; and how does this rain and its variability affect the structure and circulation of the tropical oceans?

What is the relationship between precipitation and changes in the boundary conditions at the Earth's surface (e.g. SST, soil properties, vegetation)?

How can improved documentation of rainfall improve understanding of the hydrological cycle in the tropics?

Knowledge of (1) how rainfall affects the dynamics and air-sea fluxes of the tropical upper ocean, and (2) rates of recycling of freshwater in the tropical ocean-atmosphere, remain as fundamental problems in our understanding of the climate system. It is these scientific issues to which we directed our research. In an effort to develop a coordinated approach to these problems, we brought together a group of investigators with expertise in remote sensing, numerical modeling, surface observations, analysis, oceanography and meteorology in a modest effort to coordinate several on-going studies into a coherent science investigation for TRMM. Work under this proposal focuses on the TRMM science discussed above, utilizing several planned observations and studies for Tropical Ocean Global Atmosphere (TOGA) and the TOGA Coupled Ocean Atmosphere Response Experiment (COARE). Funds were requested here only for activities relating directly to the TRMM science goals and not otherwise covered by other programs. Funding cuts during the course of the project made it impossible to complete all the objectives of the original proposal. Nevertheless, significant progress was made, as summarized below.

Surface temperature, salinity and remote sensing (Lagerloef) Temperature and salinity in the surface 3 cm of the ocean were obtained from R/V Wecoma during COARE (Lagerloef, et al, 1993; Paulson and Lagerloef, 1993). A special sampler was developed for this experiment, involving a surface towed hose drawing seawater pumped through a thermosalinograph. The objectives were 1) to study the very near surface rain response at depths much shallower than the 2 m to 5 m depths conventionally sampled with continuous shipboard sampling systems, and 2) to better understand the relationship the very near surface, or skin, properties seen by remote sensing and the bulk, or mixed layer, temperatures and salinities.

Some results from surface sampler data during heavy rainfall episodes are shown in Figure 1 in comparison to measurements made at 2 m from a sensor mounted on the ship's bow. The surface (~3 cm) showed a sharp response to the cool and freshwater rain with depressed temperatures and salinities while the response at 2 m was small by comparison, indicating that the freshwater was retained in a shallow surface lens during the active rainfall. Other low salinity/temperature anomalies not coincident with rain indicate that the ship passed through residual lenses formed by earlier rain events. These data will be included in the larger TOGA COARE data base, and used to describe the degree of decoupling between skin and bulk values caused by lens formation, the studies of mixed layer models, heat and freshwater fluxes, and freshwater budgets in the COARE IFA.

Shipboard observations and analyses (Lukas): During the IOP, R/V Wecoma towed Seasoar depth-cycling vehicles, carrying conductivity, temperature, depth (CTD) sensors to obtain high vertical and along-track resolution measurements of temperature and salinity in the upper 300 m. Repeated surveys were conducted in the butterfly pattern of the IFA. From these data, daily averages of mixed layer depth, temperature and salinity have been computed and a portion is shown in Figure 2. The mixed layer salinity decrease in early January coincides with the onset of heavy atmospheric convection and precipitation observed during the COARE IOP.

Mixed layer, isohaline, and isothermal layer depth estimates have been compared to the local momentum, heat, and moisture fluxes. Preliminary results suggest that for strong enough winds, the freshwater flux is not very important, while for weaker winds, it may make the difference between a wind event destroying the barrier layer or not. The importance of such dynamics on the structure of the upper layer and the air-sea heat flux is a fundamental scientific issue for TOGA COARE. This effort also included preliminary analysis of TAO mooring data, including rain gages, and development of a Lagrangian mixed layer model to assess the effects of advection on the salt budget and stratification.

Surface drifter observations (Niiler) TOGA COARE includes a program centered on Lagrangian techniques with satellite-tracked (ARGOS) drifters by which we can study how the upper ocean in the warm pool is forced by the wind, heated and freshened over daily to monthly time scales. Approximately 50 drifters per year, for a two year period beginning mid-1992, were programmed for the western tropical Pacific. The resulting data set will provide measurements of velocity U , temperature T and salinity S as well as dU/dt , dT/dt and dS/dt following the drifters (Niiler, 1990). Analysis objectives for this effort are to estimate the long-term average balance of dT/dt and dS/dt following the fluid parcels. Our preliminary

results indicate that our estimates will provide a strong and unique constraint on the heat budget in the warm pool region; we expect that our estimates of dS/dt will provide a similar constraint for the freshwater budget. From these, the upper ocean *in situ* convergence of freshwater will be computed to compare with rainfall. As an example of this calculation, fields of U have been collected from the Comprehensive Ocean Atmosphere Data Set (COADS) ship drift observations and fields of S have been collected from the Levitus climatology to compute the steady mean annual freshwater convergence (i.e. salinity divergence), which is the left hand side of

$$\frac{U \cdot \nabla S}{S} = \frac{E-P}{h}$$

where h is the mixed layer depth. The map of the mean annual freshwater convergence of the tropical Pacific is shown in Figure 3. The negative values (dashed contours) signify the regions where precipitation exceeds evaporation, and these clearly denote the bands of tropical rainfall in the ITCZ and SPCZ. These maps will be analyzed in conjunction with $E-P$ estimates from satellites (below) to evaluate the consistency between $E-P$ derived from the upper ocean freshwater convergence vs satellite. This can serve as an important validation tool for TRMM rain products on large spatial and seasonal to interannual time scales.

Numerical modeling (Busalacchi) In support of TOGA COARE, A. J. Busalacchi, in collaboration with Dake Chen and Lew Rothstein, studied the physical processes that are responsible for the maintenance and variability of the warm pool in the western tropical Pacific Ocean and its influence on the large scale tropical Pacific Ocean heat budget. This numerical modeling effort has highlighted mixed layer physics of the equatorial ocean, with special emphasis on upper ocean mixing and an investigation of possible salinity effects with future application to TRMM studies in mind. More specifically, this effort was designed to use a rather unique combination of explicit one-dimensional mixed layer models and a large scale tropical ocean circulation model that they have recently modified to include active hydrology. Initial experiments were configured with what were felt to be the minimum requirements to capture the physics of the tropical upper ocean and were run under idealized forcings in a model tropical Pacific basin. Subsequent experiments were designed to utilize realistic geometries under observed forcing to provide simulations of the upper tropical Pacific Ocean. The ultimate goal was the development of a computationally efficient tropical Pacific upper ocean model that would be appropriate for studies of the warm pool response to momentum and buoyancy forcing.

Evaporation, precipitation and fluxes (Liu) From the conservation principle, the ocean surface fresh water flux (evaporation-precipitation) has to be balanced by the change of water storage and the water divergence in the atmosphere. The difference between evaporation and precipitation will be primarily balanced by the horizontal water vapor transport. Each of these terms will be computed, with developing satellite methods. Precipitation can be computed as the residue of $E-P$, with evaporation computed separately from bulk formula using SSMI, and compared with satellite retrievals. This is the core of one of the on-going studies of W.T. Liu, presently supported by the NASA Interdisciplinary Science and Hydrologic Cycle Programs. The present TRMM project has been carried out in collaboration to include the hydrologic balance in the ocean, with the focus in the tropical Pacific, utilizing salinity and current measurements from other co-investigators and from TOGA COARE.

VIRS team leader and VIRS validation (Lagerloef) An interim VIRS science team was formed in 1992 from a subset of TRMM Project Science Team members with interest in the VIRS data, and Lagerloef was appointed chairman. The VIRS team provided scientific guidance to the TRMM Project regarding VIRS hardware and calibration issues. Certain hardware issues were monitored. Of greatest concern are the 12 micron channel sensitivity and the performance of the radiative cooler.

Salinity Remote Sensing (Lagerloef and Swift) We originally planned to make salinity remote sensing observations from the NASA DC-8 during TOGA COARE, but it was not possible to include ESTAR on that or any other aircraft designated to participate in the field program. Alternatively, we proceeded with a plan to make observations from a radiometer mounted on the R/V Wecoma during Leg 3 of the COARE IOP. The radiometer measurements are consistent with modeled values for salinity, temperature and incidence angle. However, as luck would have it, there was very little rain encountered by the ship and consequently no significant salinity variations observed by the in situ calibration sensors, during the portions of the Leg 3 cruise when the radiometer was operating. As such, we did not achieve the primary objective of calibrating the sensor response to oceanic salinity variations in the warm pool.

Publications and Presentation Abstracts

Chen, D., L. M. Rothstein, and A. J. Busalacchi, 1993a. A hybrid vertical mixing scheme and its application to tropical ocean models. Submitted to J. Phys. Oceanogr.

Chen, D., A. J. Busalacchi, and L. M. Rothstein, 1993b. Simulation of the seasonal cycle in the tropical Pacific Ocean. In preparation for submittal to JPO, 8/93.

Huyer, A., M.Kosro, C.Paulson, R.Lukas, E. Firing and P.Hacker, 1993: Thermohaline structure of the upper ocean in the COARE Intensive Flux Array. *EOS Trans. AGU*, 74, 1993 Fall Meeting (Abstract).

Lagerloef, G., C. Swift and D. LeVine, 1995: Sea surface salinity: The next remote sensing challenge. *Oceanography* (*submitted*)

Lagerloef, G., C. Paulson, J. Aleksa and C. Wilson, 1993: Rain-caused near surface salinity fluctuations in the western Pacific warm pool during TOGA COARE (Abstract), Third Scientific Meeting of the Oceanography Society, Seattle, Wa.

Lagerloef, G.S.E., C.T. Swift, D.M. Le Vine and A. Griffis, 1992, "Remote Sensing of Sea Surface Salinity: Airborne and Satellite Concepts," AGU Ocean Sciences Meeting, New Orleans, January 1992 (Abstract).

Li, X. and P.Niiler, 1994: Wind driven current in the upper mixing layer over the equatorial Pacific Ocean. *EOS Trans. AGU*, 75, 1994 Ocean Sciences Meeting (Abstract).

Lukas, R. 1993: The TOGA COARE westerly wind burst and the oceanic response. Abstracts of the Air-Sea Interaction Symposium, Oct. 25 1993, Sendai Japan.

Lukas, R. and P. Webster, 1993: TOGA COARE: Ocean and atmosphere Interactions I. *EOS Trans. AGU*, 74, 1993 Fall Meeting (Abstract).

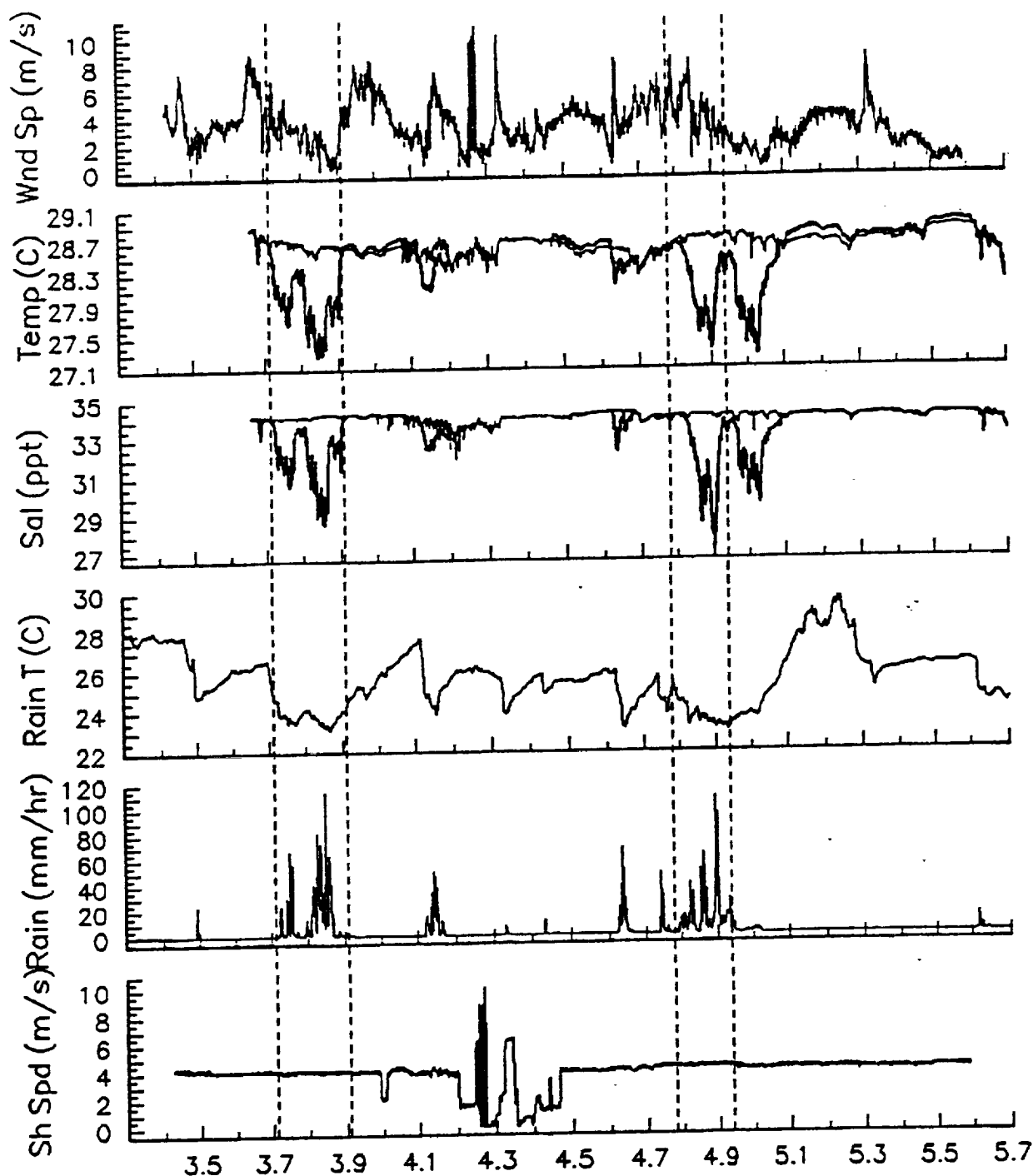
Lukas, R., E. Firing, P. Hacker, A. Huyer, M. Kosro, C. Paulson, 1993: The upper ocean response to the December 1992 westerly wind burst. *EOS Trans. AGU*, 74, 1993 Fall Meeting (Abstract).

Paulson, C.A. and G. Lagerloef, 1993: Fresh surface lenses caused by heavy rain over the warm pool of the western Pacific Warm Pool during TOGA COARE, *EOS Trans. AGU*, 74, 1993 Fall Meeting (Abstract).

Shinoda, T and R. Lukas, 1995: Lagrangian mixed layer modeling of the western equatorial Pacific. *J. Geophys. Res.*, in press.

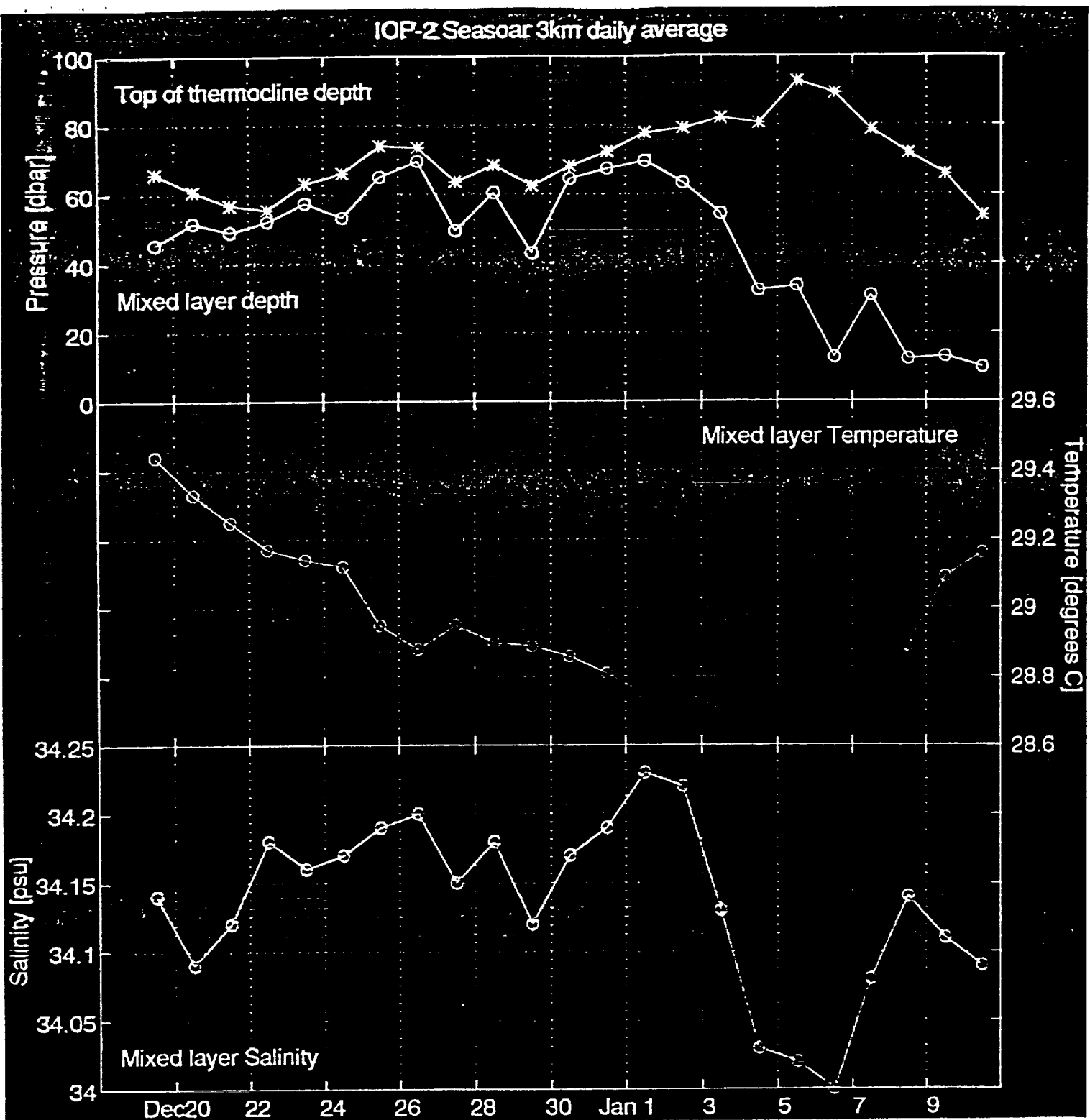
Soloviev, A., R. Lukas, S. Asghar, D. Khlebnikov, 1993: Coherent structures near the air-sea interface in the western Pacific warm pool. *EOS Trans. AGU*, 74, 1993 Fall Meeting (Abstract).

Figure 1



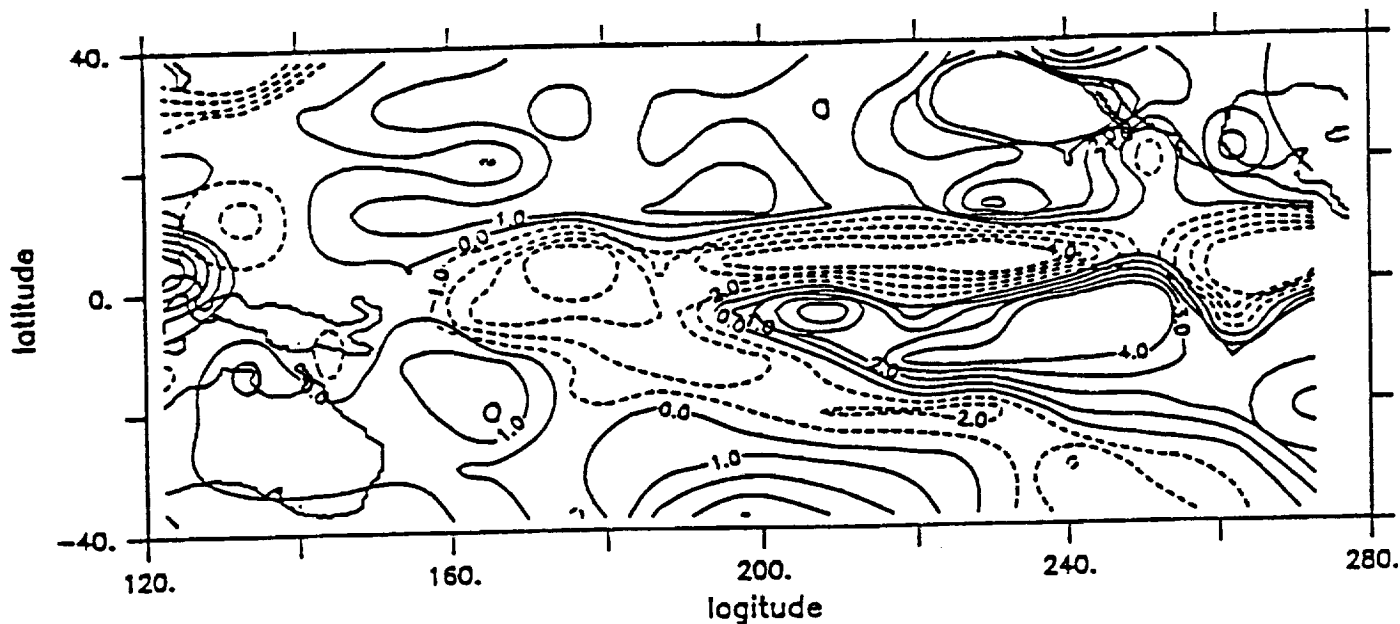
TOGA COARE measurements from R/V Wecoma, Leg 2 (14 Dec 1992-16 Jan 1993). Top to bottom: wind speed; surface (dark line) and 2 m (light line) temperature; surface and 2 m salinity; rain temperature; rain rate and ship speed. Abscissa is day of year in 1993 (3.0=0000 GMT 3 January, 1993). Conspicuous dilution took place during the heavy rain episodes (indicated by the vertical dashed lines), forming shallow lenses of cooler, fresher water. Signatures at the 2 m depth were much smaller than at the surface. After the second large rainfall episode, the ship passed through a low salinity lens remnant from an earlier rainfall. (From Paulson and Lagerloef, 1993).

Figure 2

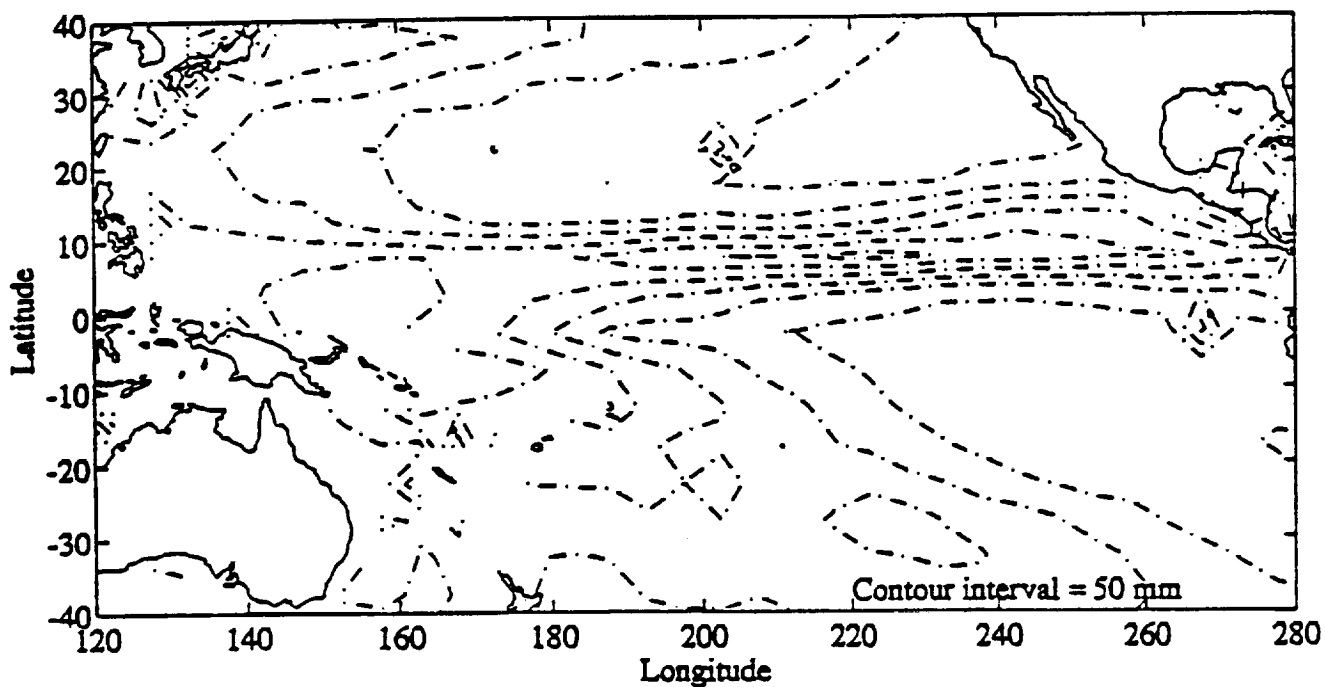


Daily average estimates based on shipboard Seasoar CTD data in the TOGA COARE Intensive Flux Array (IFA), Dec 1992 - Jan 1993: Top panel: mixed layer depth h and depth of the top of the thermocline; Middle panel: Mixed layer temperature T ; Bottom panel: Mixed layer salinity S . Such estimates of h and S will be used with other measurements to estimate the freshwater budget within the IFA.

Figure 3



Estimate of the mean annual freshwater convergence $(U \cdot \nabla S)/S$ based on COADS ship drift data for U and Levitus climatology for S . This yields an estimate of $(E-P)/h$, where h is the mixed layer depth. The dashed contours, where $E-P < 0$, coincide with the heavy precipitation zones of the ITCZ and SPCZ.



GPCP mean annual monthly rainfall from SSMI data (Chang, et al, 1993). Note that the bands of high precipitation coincide with the estimates of freshwater convergence from ocean surface data

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE January 1995	3. REPORT TYPE AND DATES COVERED Contractor Report	
4. TITLE AND SUBTITLE NASA TRMM Effects of Tropical Rainfall in Upper Ocean Dynamics, Air-Sea Coupling and Hydrologic Cycle			5. FUNDING NUMBERS Code 910 NAS5-31358	
6. AUTHOR(S) Principal Investigator: Gary Lagerloef				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Science Applications International Corporation 13400 Northup Way, NE Suite 36B Bellevue, WA 98005			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) NASA Aeronautics and Space Administration Washington, D.C. 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER CR-189437	
11. SUPPLEMENTARY NOTES Technical Monitor: O. Thiele, Code 910				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category: 43 Report available from the NASA Center for AeroSpace Information, 800 Elkridge Landing Road, Linthicum Heights, MD 21090; (301) 621-0390.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This was a Tropical Rainfall Measurement Mission (TRMM) modeling, analysis and applications research project. Our broad scientific goals addressed three of the seven TRMM Priority Science Questions, specifically: What is the monthly average rainfall over the tropical ocean areas of about 10 ⁵ km ² , and how does this rain and its variability affect the structure and circulation of the tropical oceans? What is the relationship between precipitation and changes in the boundary conditions at the Earth's surface (e.g., SST, soil properties, vegetation)? How can improved documentation of rainfall improve understanding of the hydrological cycle in the tropics?				
14. SUBJECT TERMS Tropical Rainfall, Tropical Ocean Global Atmosphere (TOGA), Upper-Ocean Dynamics, Air-Sea Coupling, Hydrologic Cycle			15. NUMBER OF PAGES 9	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	